Chemical Engineering at Orbital ATK

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March 22, 2016
University of Utah Chemical Engineering Seminar

Overview

- **Goal: Give a snapshot of what a chemical engineer might expect to do in the aerospace industry through the experiences of two different engineers at Orbital ATK**

- Company description
- Product description
- Shelby’s experiences
- Justin’s experiences

About Orbital ATK

- $4.5 billion global aerospace and defense systems company
- Industry leader in government, defense and commercial markets
- Employs ~12,500 people, including ~4,300 engineers and scientists
- Major locations in 8 states (Virginia, Maryland, West Virginia, Minnesota, Missouri, Utah, Arizona and California), plus smaller locations and employees based in another 12 states
- Corporate headquarters in Dulles, Virginia
- This is a very exciting time for Orbital ATK. This is a unique strategic convergence of two companies that have worked together for more than 25 years
- Orbital ATK is financially strong and highly competitive in the aerospace and defense sector based on the company's focus on the innovation, reliability, and affordability of its products
- Go to www.orbitalatk.com for more information

Company Overview

Flight Systems Group
- Space Launch Vehicles
- Rocket Propulsion Systems
- Missile Defense Systems
- Aerospace Structures

Defense Systems Group
- Tactical Missile Products
- Defense Electronic Systems
- Armament Systems
- Ammunition and Energetics

Space Systems Group
- Commercial Satellites
- Government Satellites
- Spacecraft Components
- Space Technical Services

Flight Systems Group

Solutions for space, defense, and commercial markets

- **Propulsion for space exploration, commercial launch vehicles, strategic and missile defense**
- Composite structures for military and commercial aircraft
- Military flares and decoys
- Space engineering services

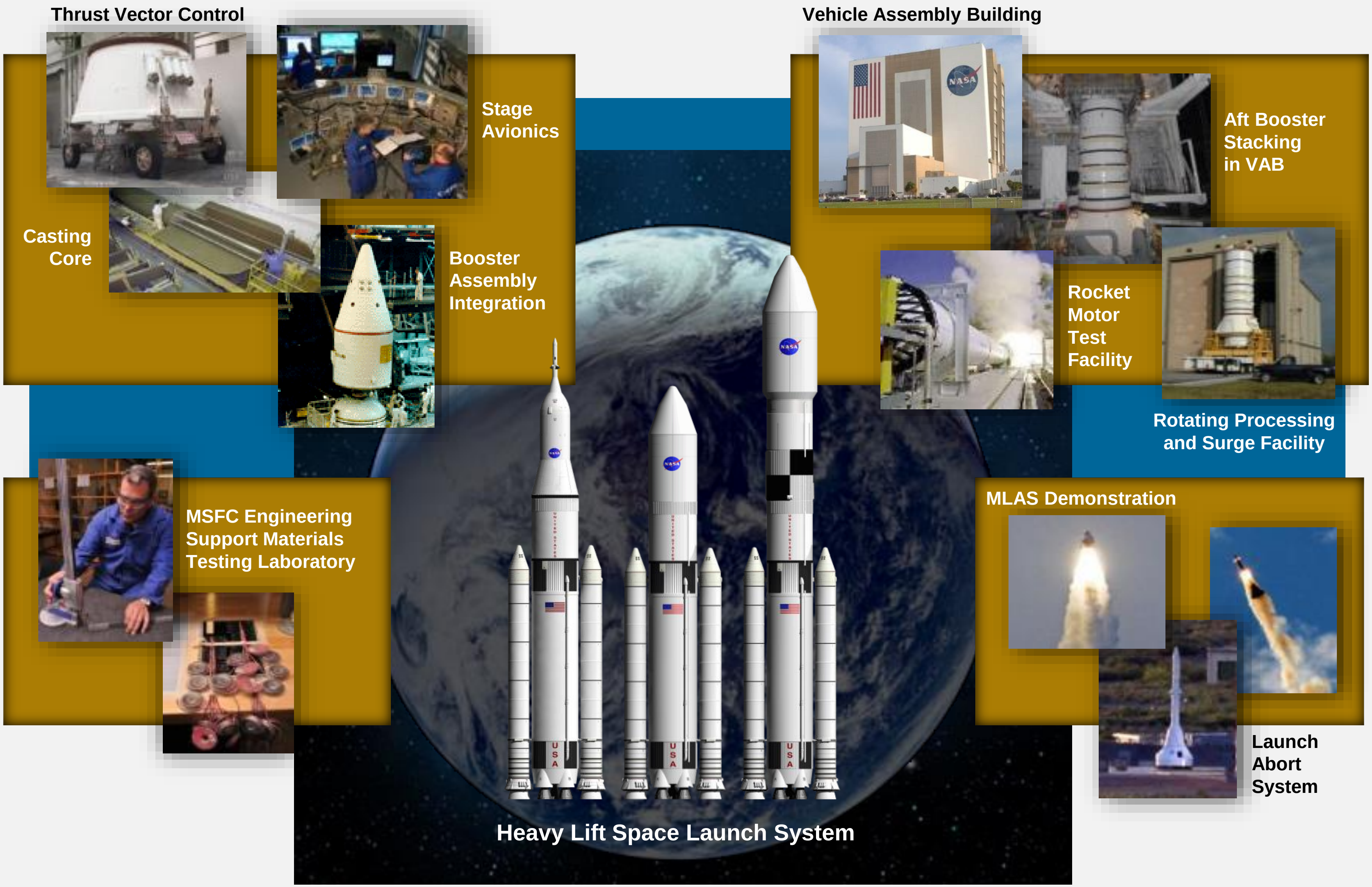
Working at Orbital ATK as a Chemical Engineer

Position	Organization	Primary Responsibility
Analysis Engineer (AE)	Analysis Engineering	AE is the technical authority for his discipline. The AE's charter is to ensure performance requirements are properly dispersed and met and providing boundary conditions or performance requirements for component /vehicle design.
Design Engineer (DE)	Design Engineering	DE is the technical owner of his/her component. The DE's charter is to define the engineering requirements necessary for their design area to perform within specification & often times statistical expectation.
Manufacturing Engineer (ME)	Operations	ME is the process owner of his/her component. The ME's charter is to define the manufacturing process that meets or exceeds both the engineering and processability requirements levied by the DE & Orbital ATK.
Quality Engineer (QE)	Quality	QE is the inspection process owner of his/her component. The QE's charter is to define the proper inspection steps and methodologies that ensure the design intent, engineering specifications and process requirements are satisfied.
Systems Engineer (SE)	Science and Engineering	Derive system level requirements, system architecture, perform functional analysis, trade studies, verification of customer requirements

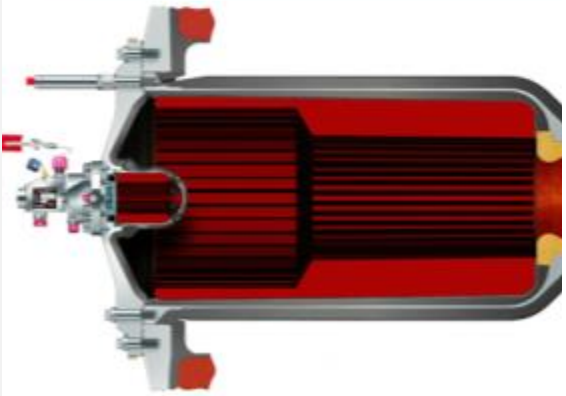
Other engineering disciplines:

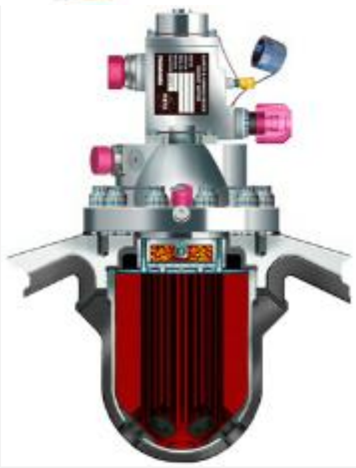
- Project Engineer
- Tooling Engineer
- Materials

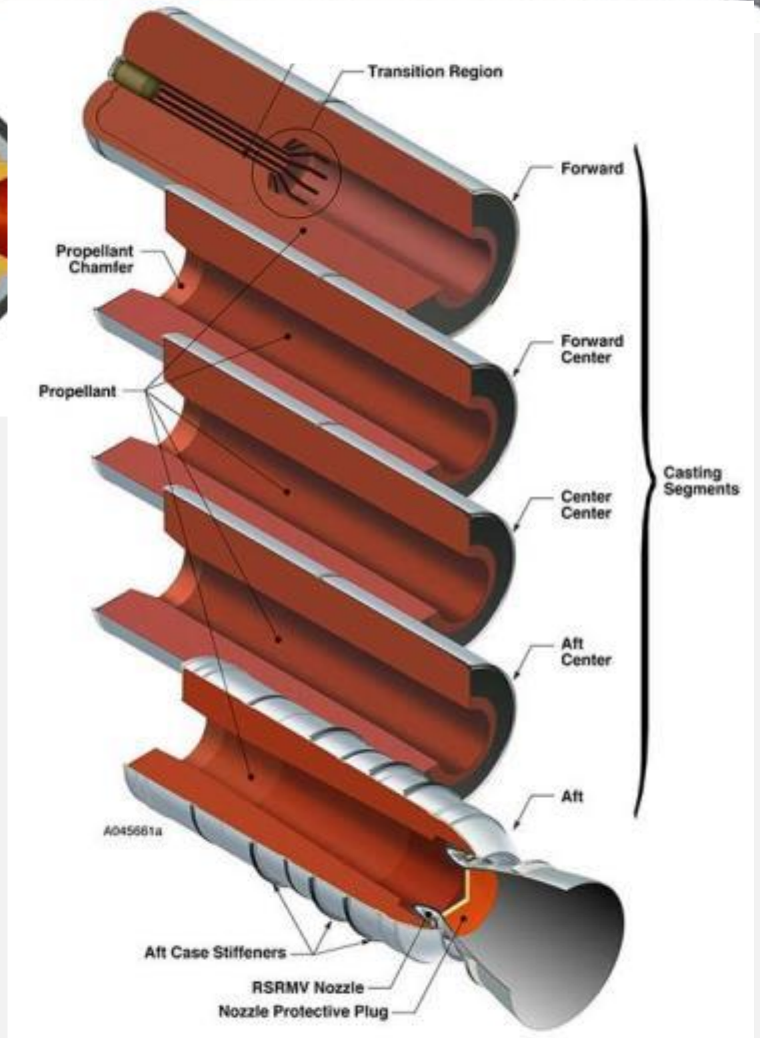
SLS Program Summary



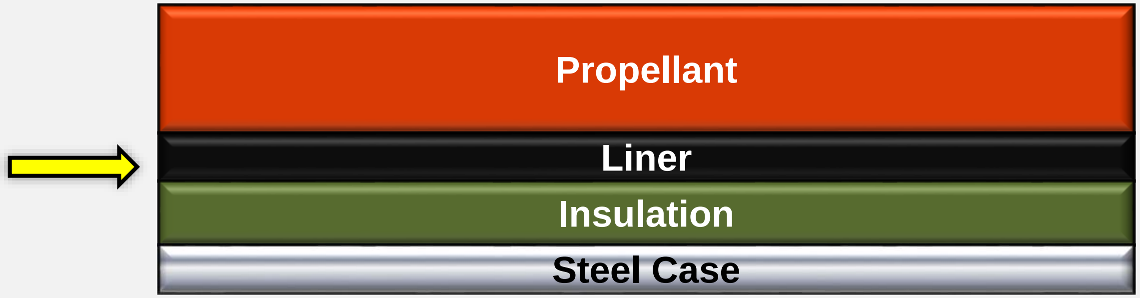
Booster Overview



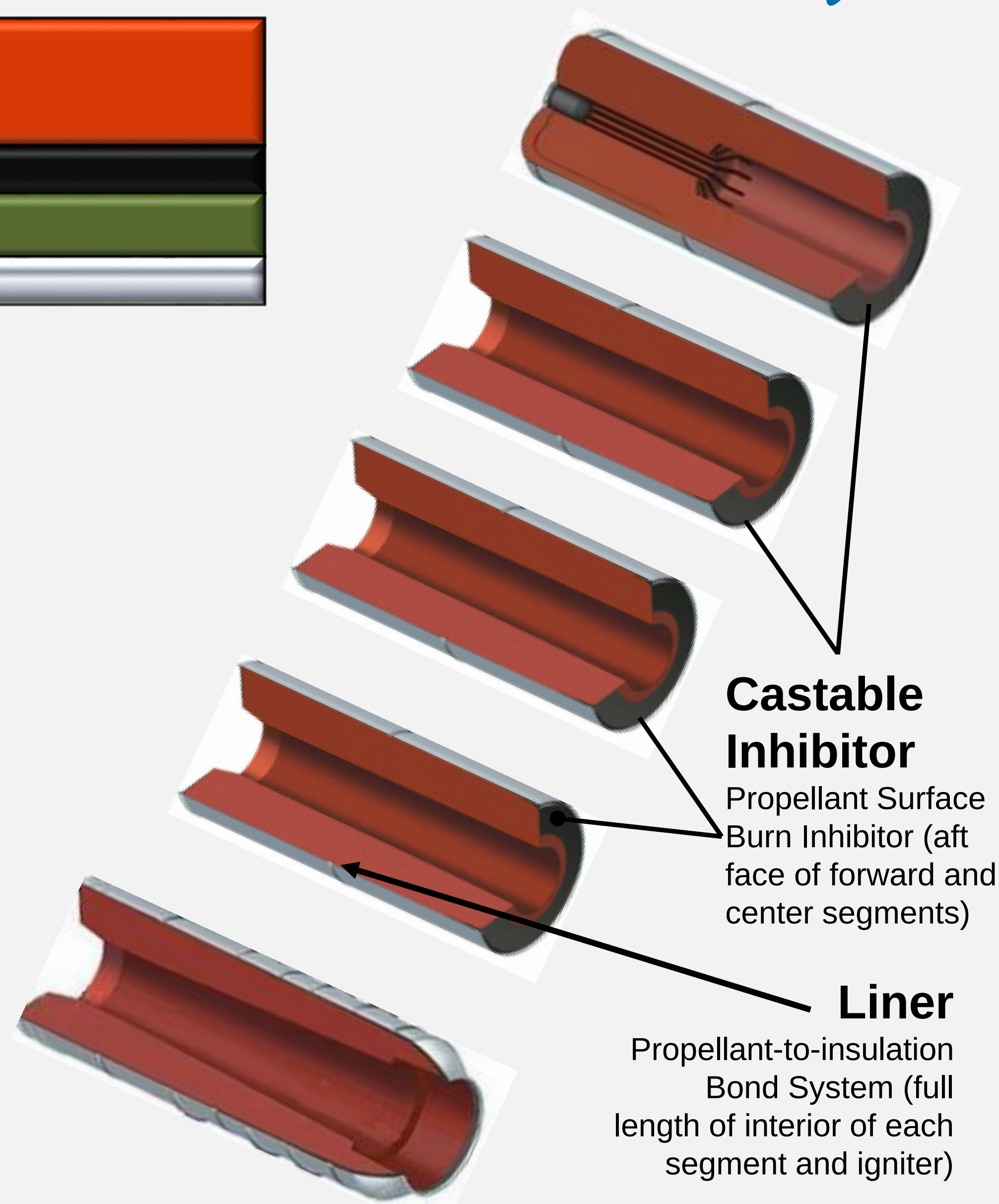




Liner



- Liner provides bonding between propellant and internal insulation
  - ➢ Liner/insulation bond is primarily a physical bond (insulation has a textured-surface to enhance bonding)
  - ➢ Liner/propellant bond is primarily a chemical bond
- Liner, like insulation and propellant, is a viscoelastic material: mechanical response changes based on the rate and time period of applied load



Liner Mixing & Application

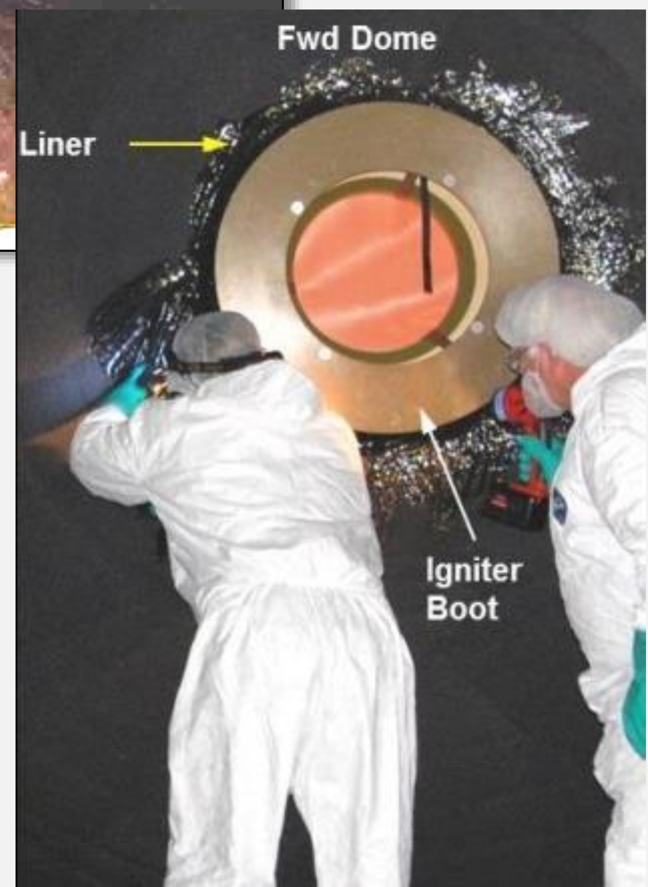
- Hand line application of SLS forward segment requires one medium size liner mix
  - Applied with segment in horizontal position
- Sling line application of SLS segments requires two large liner mixes
  - Applied with segment in vertical position

Liner Application Methods

Sling Lining Disc

- Slinger disc turns at > 10,000 RPM
- Sling liner disc does not pivot requiring hand lining
- Segment cured at elevated temperature for about two days

Hand-line Application



- Igniter boot, dome region, and first factory joint on forward segments are hand applied with a medium sized liner mix (thixotrope increased to prevent liner slump/sag)
- Applied with segment in horizontal position
- The liner is applied to insulated segment with a weight requirement

Liner Post-Cure Inspection - OLD

Inspected for “full coverage”

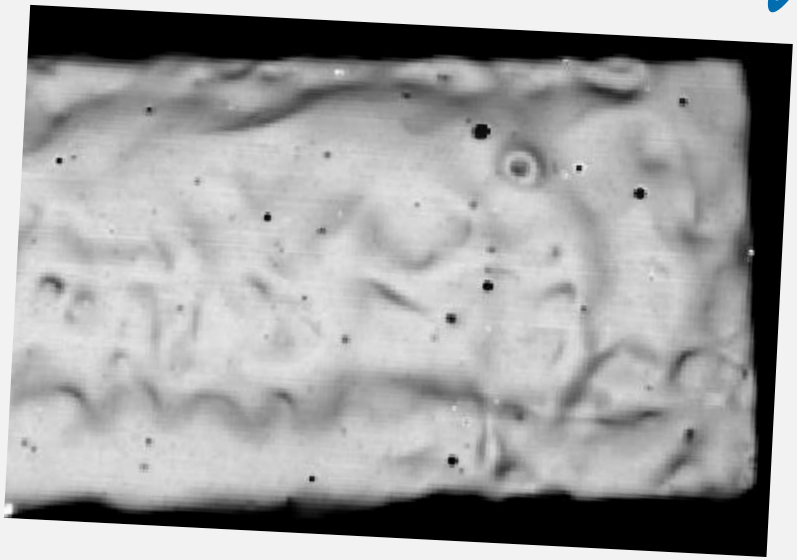
- Thickness not measured: weight requirement with known surface area
- Prior to liner cure, an operator is lowered into segment (personned basket) to verify full coverage
  - Liner voids are reworked if found
- After liner pre-cure, operators and inspectors are lowered into the segment to verify full coverage
  - Any liner voids found are repaired with liner saved from the liner used for sling application
  - Repair liner will cure during segment pre-heat prior to propellant cast

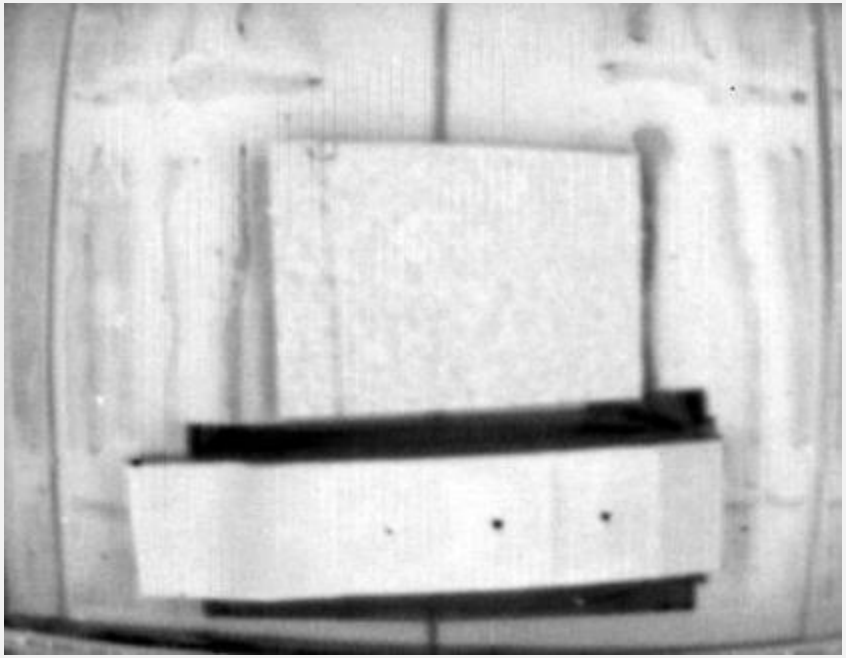
Liner Inspection

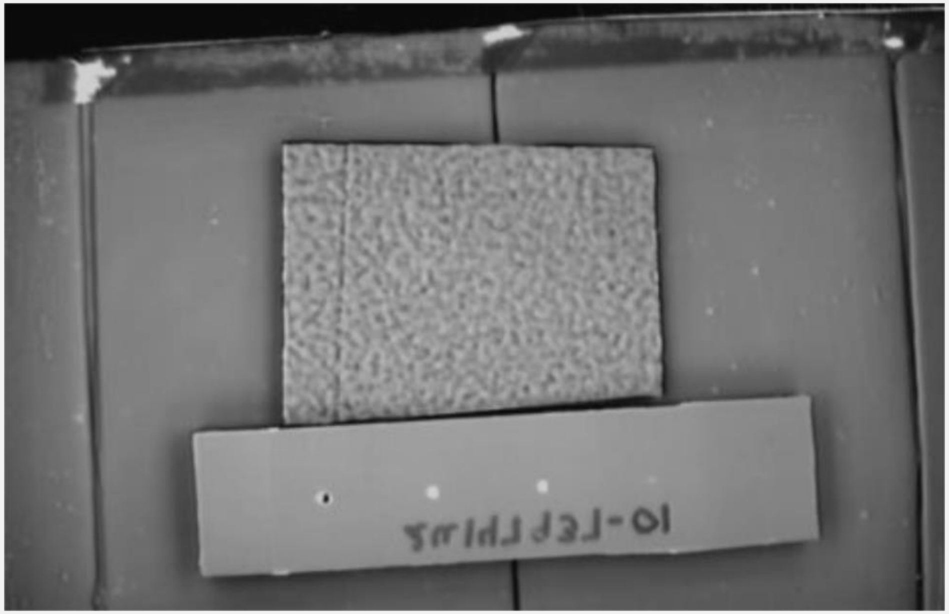
The segment must be cast with propellant within about three weeks after liner cure to ensure adequate liner cure potential remaining

During this time witness panels are tested to verify tensile strength of the liner/insulation system

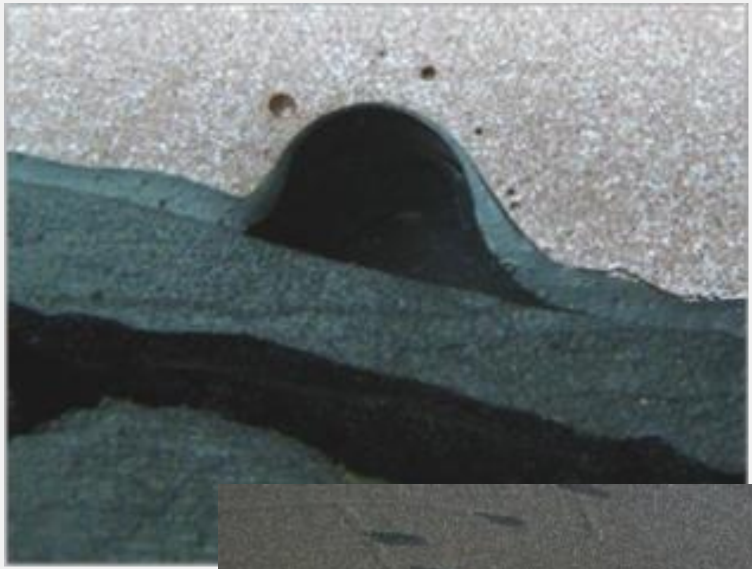
Liner Post-Cure Inspection – NEW Flash Thermography

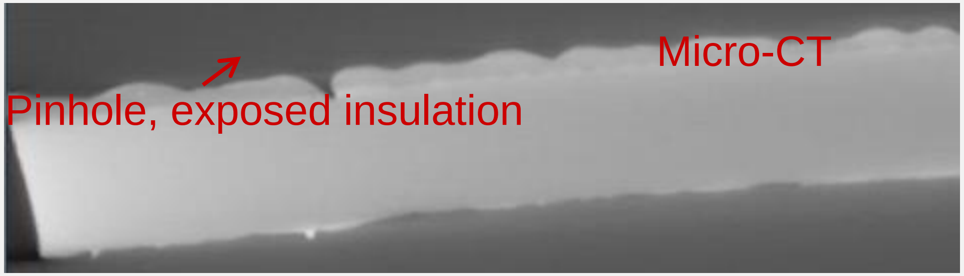






Inspection – Liner Witness to Offgassing





Liner Witness Panels

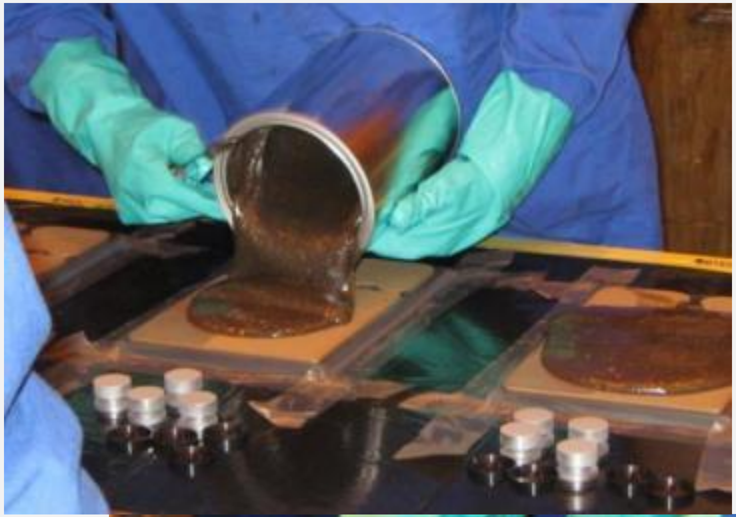
- Witness panels are processed side-by-side with the segments
  - Segment witness panels include tensile buttons and peel strips that test the critical bond interfaces

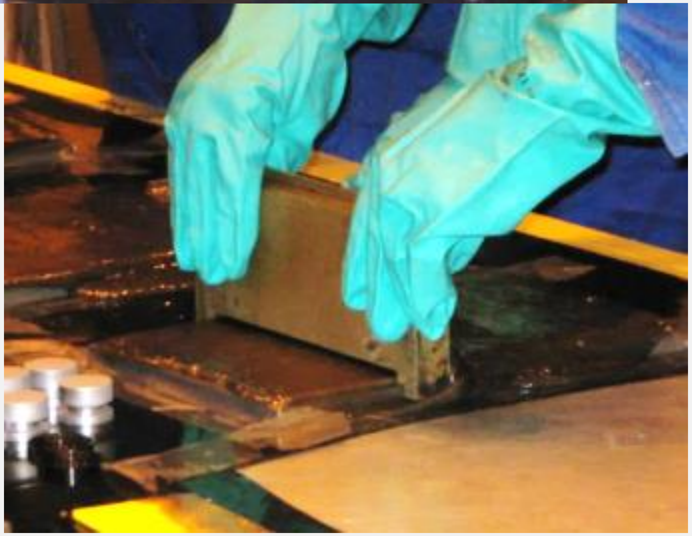
Liner-Insulation Bondline

Liner-Propellant Bondline

Witness Panels – Screed vs Sling

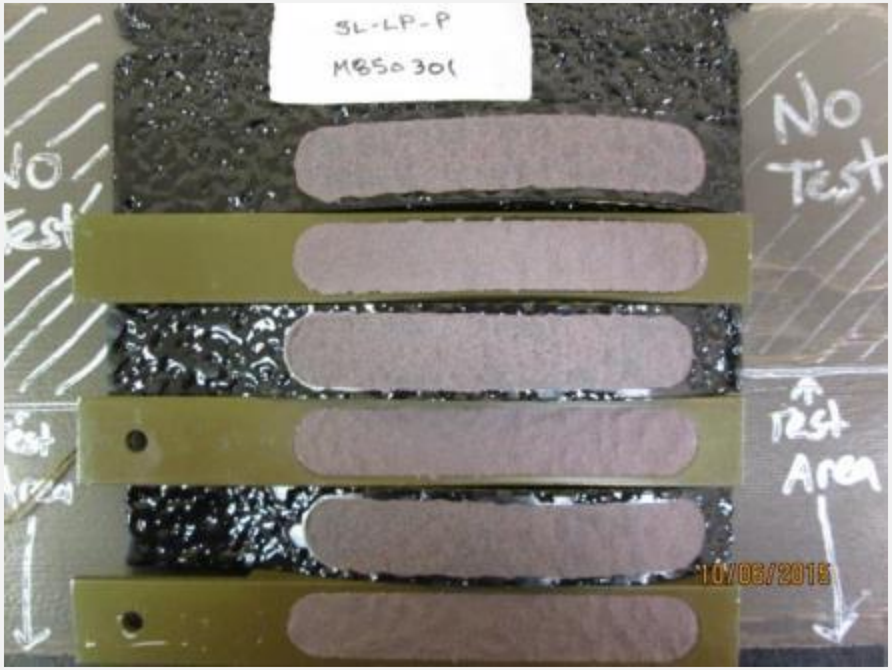
- Motor experiences sling line application while witness panels experience screed application



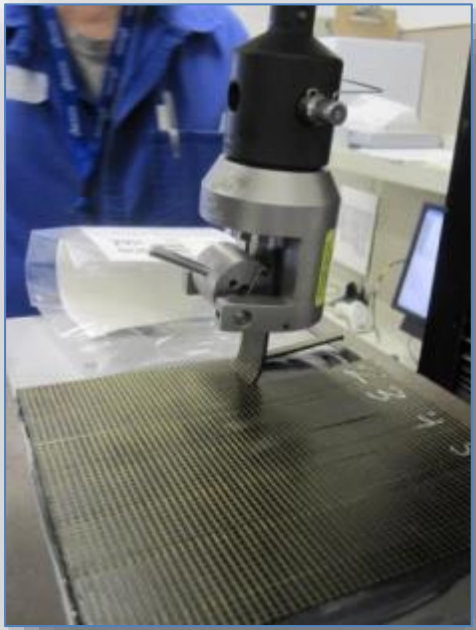


Witness Panels – Screed vs Sling

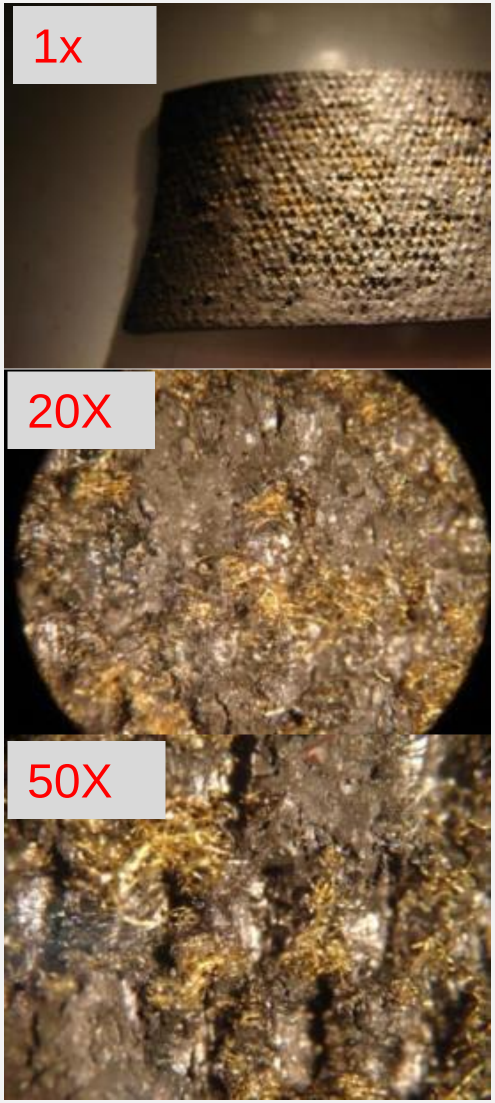
- Effort to sling line panels showed that it is more difficult to test uneven surface texture of sling line application



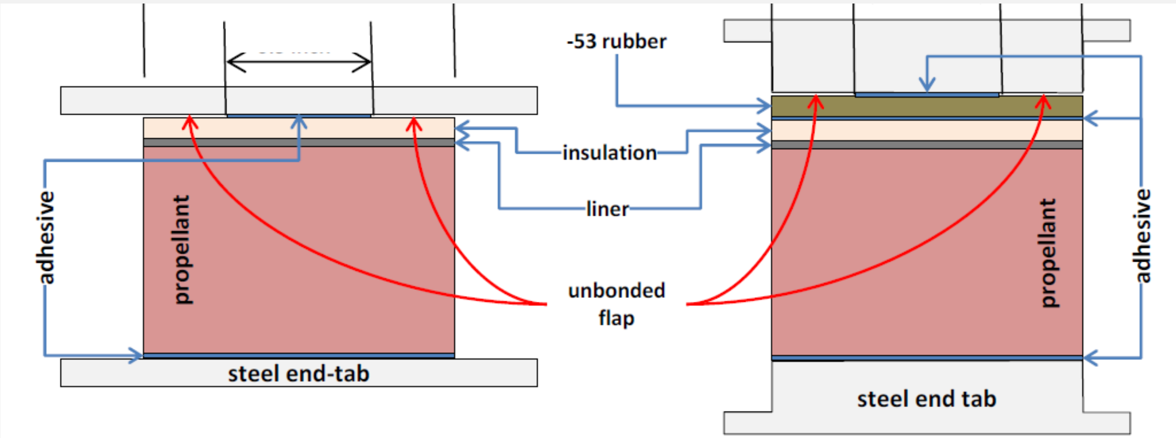
Witness Panel Testing - Instron

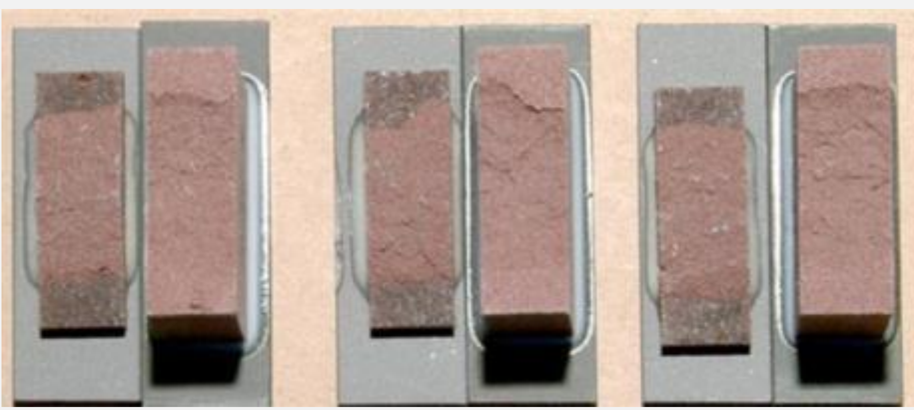


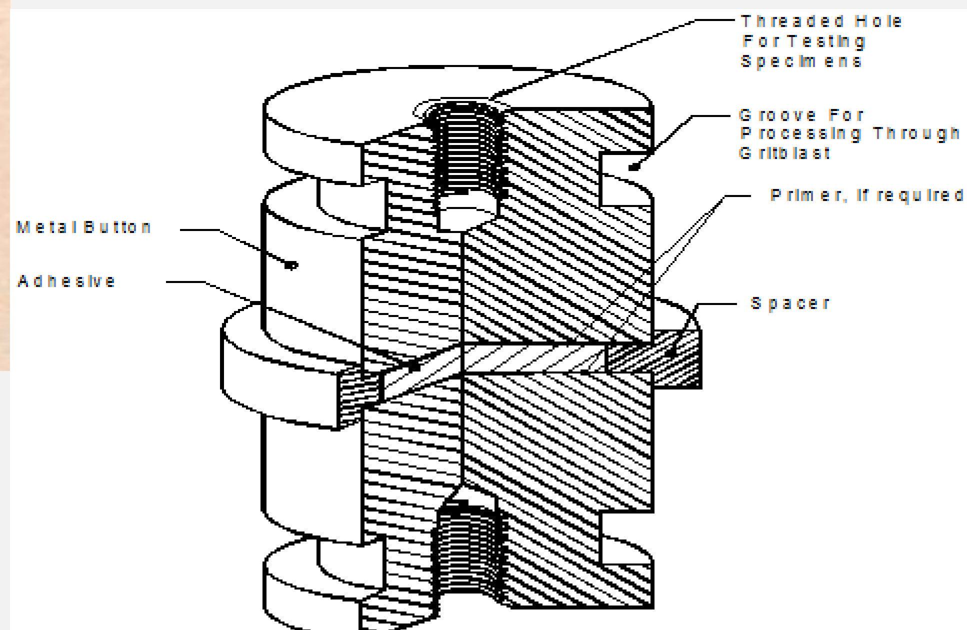
Witness Panel Failure Mode Shift



Test Specimens – AFT, Tensile Buttons

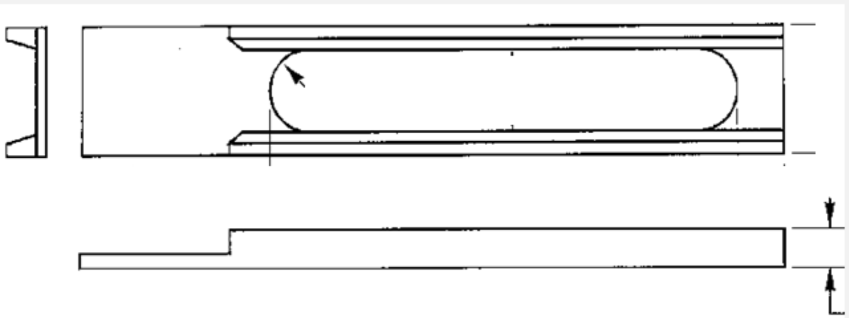




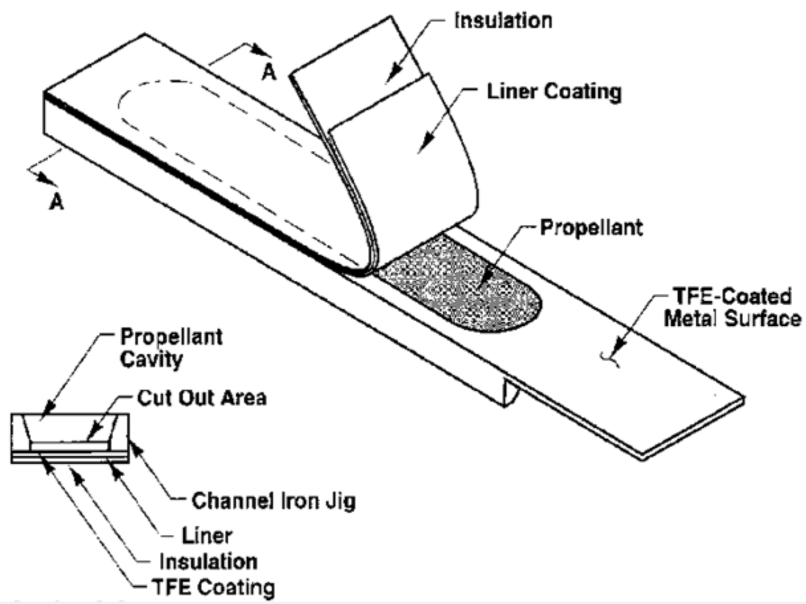


Test Specimens – Peels, FLS

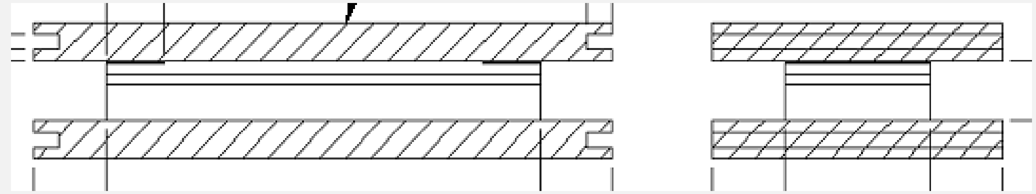
180° Peel Board Configuration

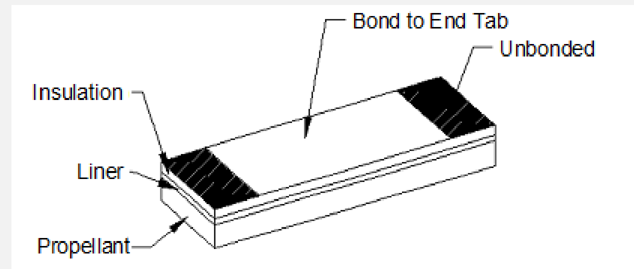


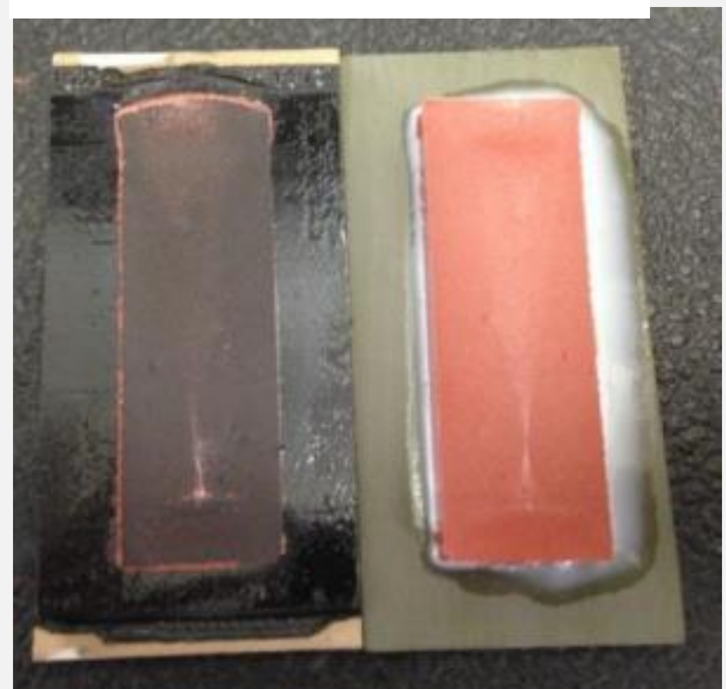
Propellant Peel Jig



Flapped Lap Shear Configuration



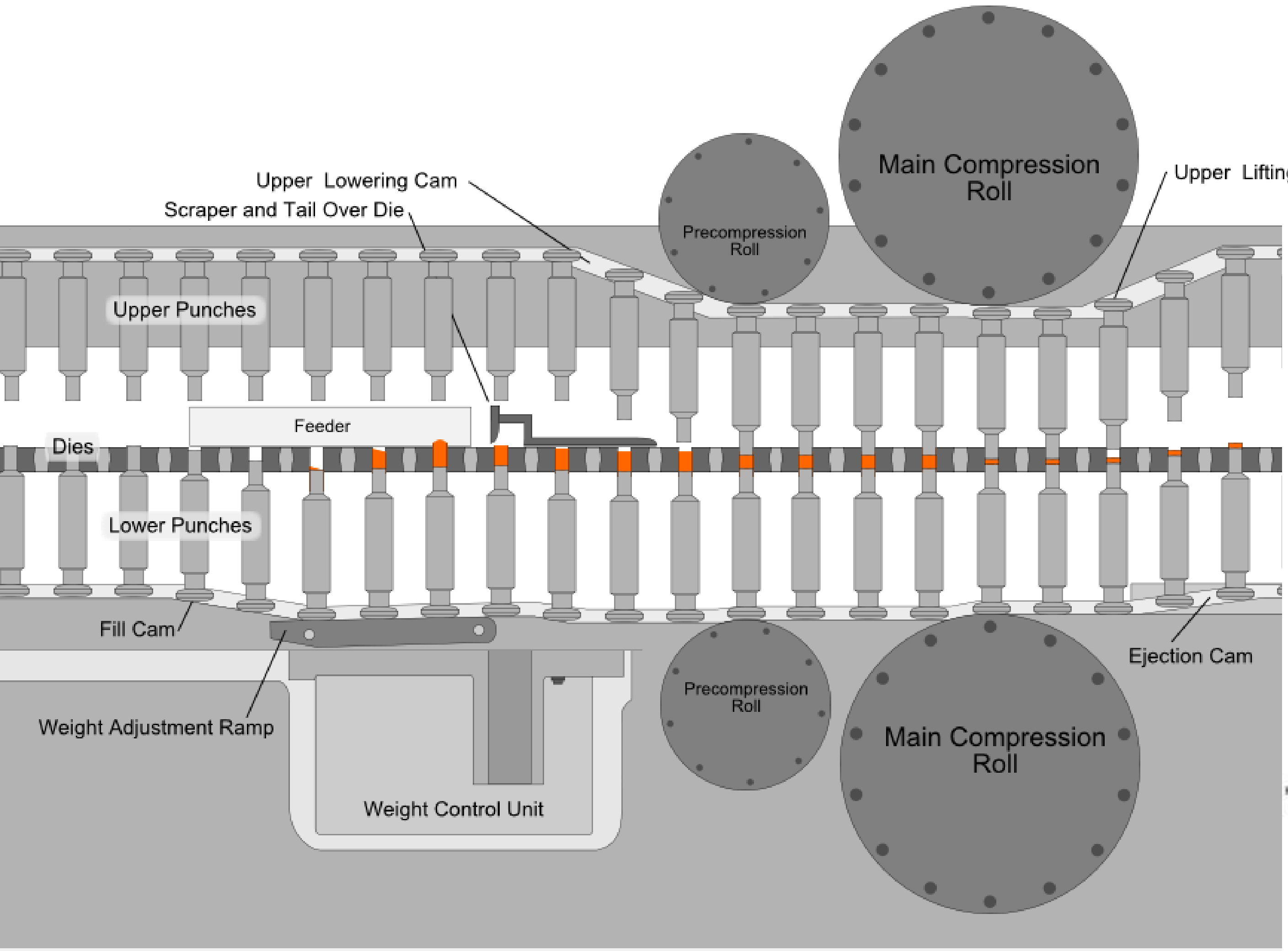




Test Specimens – Dogbones, Slump

Orbital ATK

Variety of Projects: BKNO3 Pelletization



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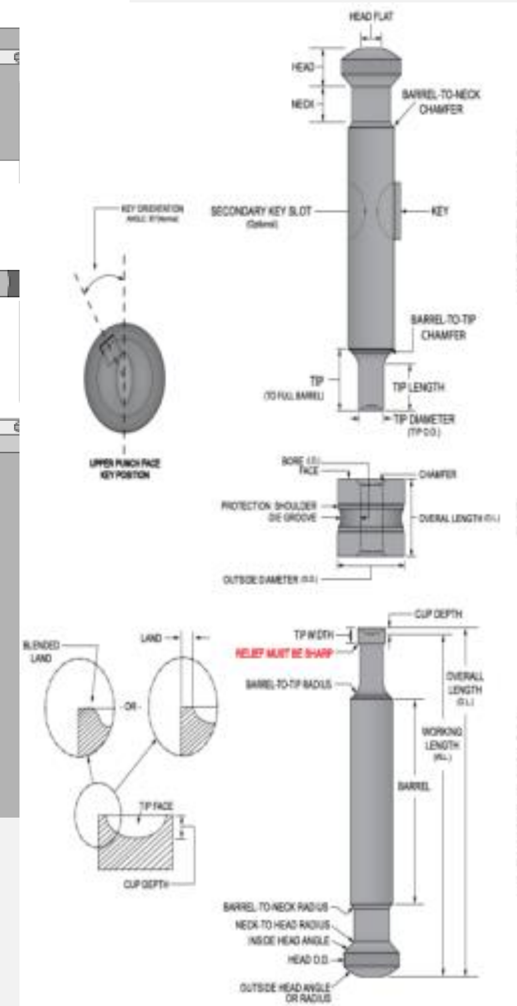
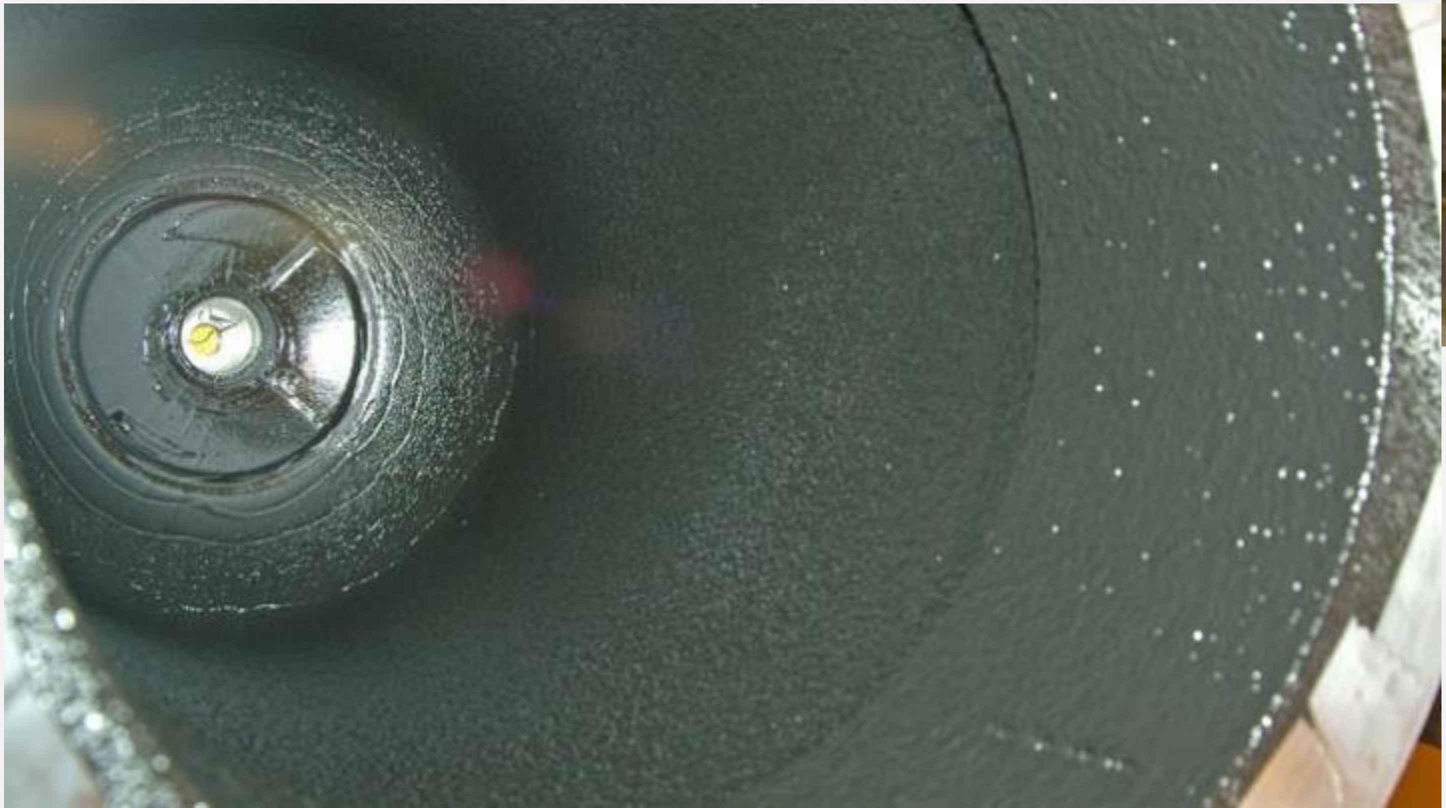
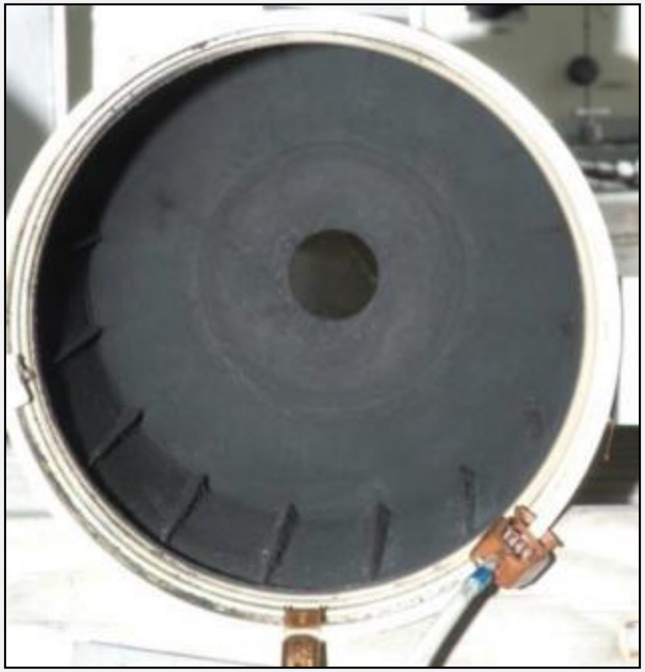


Variety of Projects: Booster Separation Motors



Variety of Projects: BSM Post-Fire Assessment

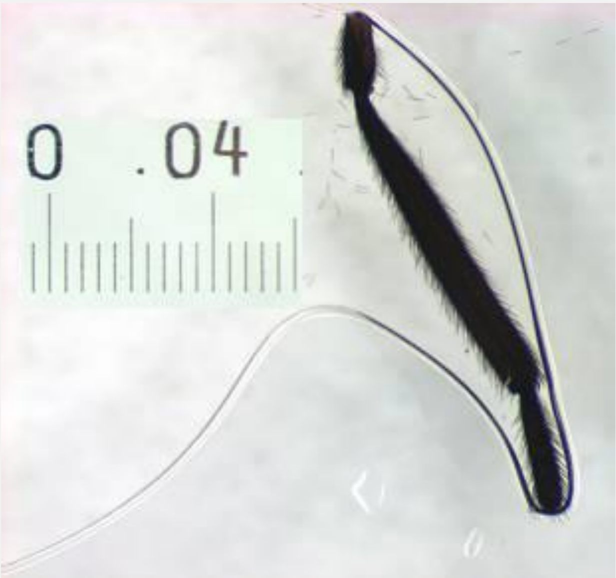


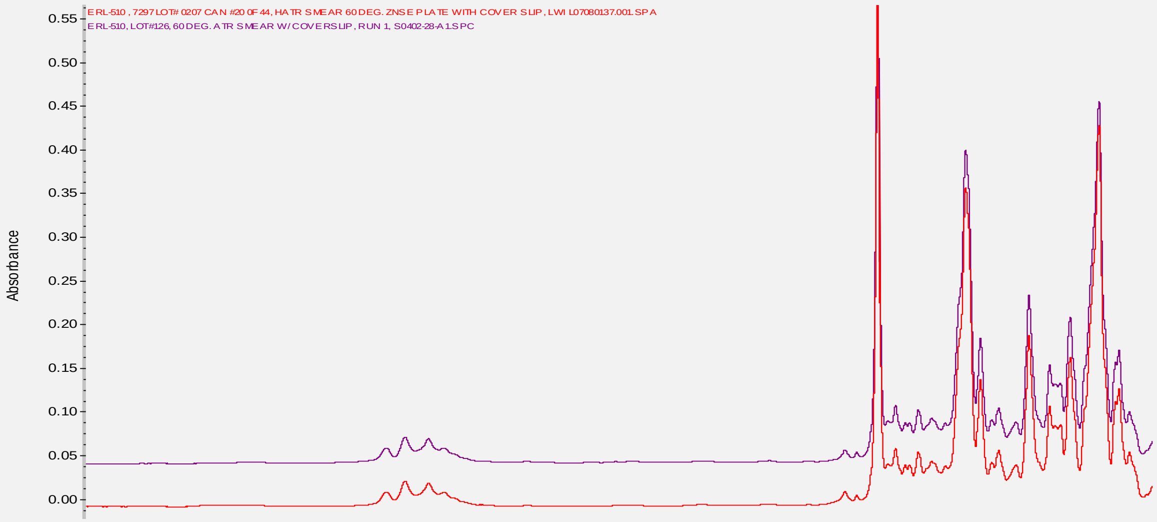
Post-fire Assessment

- BSM Nominal Liner Condition
  - Loose char covering the ID of the case
  - More erosion in the propellant valleys than the fins
  - Slivers of propellant at the fin centers after post-flight
    - No remaining propellant after static test
  - Heat affected igniter liner swells and becomes brittle
- BSM Liner Evaluation
  - Erosion patterns are visually inspected
  - Thickness of remaining virgin material is measured
  - Bondlines are examined

Nonconformance

- Contamination
  - Crayons
  - Conveyor belt - vendor
  - Grease - cranes
  - Bugs - spider legs
  - Out-of-place process materials
- Liner Cure Issues
  - Under cured
  - Over cured
  - Wrong temperature
- Processing parameter violations
  - Humidity
  - Flow rate
  - Mix speed, weights, temperature
- Shelf life issues
- Test results violations
  - Raw materials
  - Liner specimens





Digital Image Correlation and Structured Light 3D Scanning

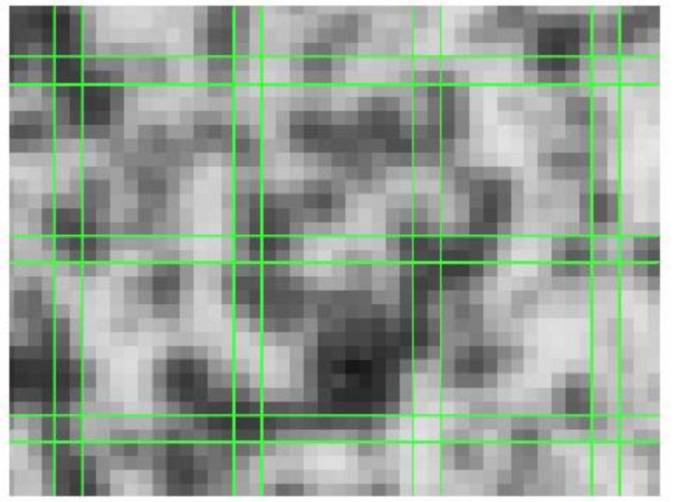
- Digital image correlation is a generic term that describes a noncontact optical method of tracking changes to an object's surface through successive digital images in 2D or 3D space
  - ➢ Object changes at the image pixel level are correlated to strain and displacement using basic measurement inputs and pixel recognition tracking software
- The ARAMIS system measures changes to an object during a deformation event and provides a means for dynamic measurement and analysis
  - ➢ Essentially uses pixels as strain gages and creates a strain field
  - ➢ Surface is often speckle coated to provide pixel contrast
- Structured Light can measure changes to an object before and after a deformation event and provides a means for static measurement and analysis
  - ➢ Measurement scans create a 3D geometry of the object which can also be compared to a nominal CAD model for as-designed to as-built deviation analysis
- Results for both methods are often compared to FE model predictions for model validation and optimization

ARAMIS System

ATOS Structured Light Scanner

Basics of ARAMIS Dynamic Deformation Measurement

- ARAMIS equipment is highly mobile and can be tailored to lab and in-field measurements
- ARAMIS software allocates coordinates to the image pixels
  - The first image represents the undeformed state to which all images are compared for deformation calculations
- The measurement object is speckle coated to provide the grayscale distribution contrast necessary to track pixel movement
- The pixel grouping size and overlap are used to define and optimize the mesh density (facet field)
  - Facet size = dimension in pixels (virtual gauge areas)
  - Facet step = distance in pixels of adjacent facets
  - Computation size = # of adjacent facets in strain calculation
- Strain is calculated at each node in the mesh based on the measured displacement of the adjacent pixel groupings



Facet Field Overlay on Speckle Surface

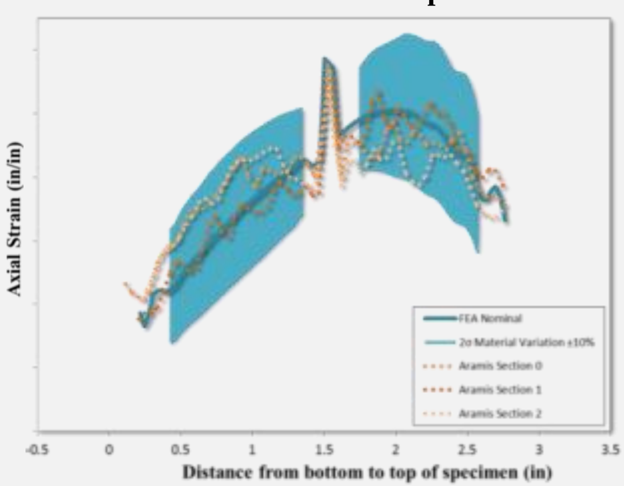
Presets	facet size	30			
	facet step	10			
	fovx	465.9	**[mm]**	18.343	**[in]**
	computation size	5			
Expected Results	total points with 12M cameras	125829			
	strain sensitivity	0.011			**[%]**
	strain sensitivity	111			**[ue]**
	equivalent gage length	4.55	**[mm]**	0.179	**[in]**
	in plane displacement sensitivity	3.11	**[um]**	0.000	**[in]**
	out of plane displacement sensitivity	15.53	**[um]**	0.001	**[in]**
	Point Spacing	1.14	**[mm]**	0.045	**[in]**
	Dot Size	0.57	**[mm]**	0.022	**[in]**

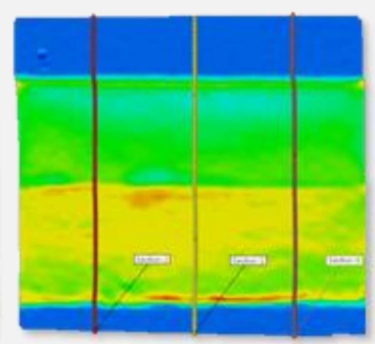
Typical Sensitivity of 12M System

ARAMIS Application: PLI FEA Model and Material Validation

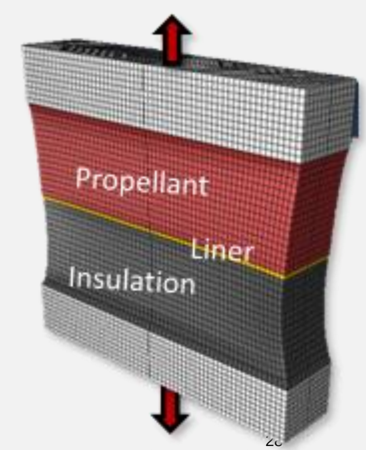
- Solid rocket motor propellant and internal insulation have a time and temperature dependent nonlinear material response
  - Numerical models incorporate master curves to predict stresses in actual hardware but these models require validation
- ARAMIS testing provided quantification of model accuracy and allowed for tuning to identify sources of error or bias
- Model was validated with stress/relaxation loading (thermal stresses during motor storage); however, bi-rate loading (a motor ignition event) did not match
  - These results emphasized that a linear elastic material model may not be sufficient, which resulted in work to develop a more refined hyper-viscoelastic material model

Relaxation Strain Comparison





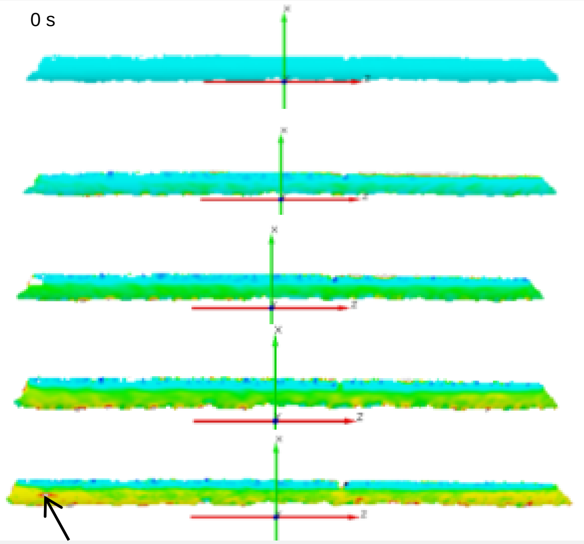
Full Strain Field of the Sample Produced by ARAMIS



FEA Models Predicted Strain and Load

ARAMIS Application: SLS Booster FSTA-1 &-2 Forward Skirt Structural Testing

- SLS ultimate assent loads are approximately 40% higher than historical shuttle loads; however, NASA wants to use the heritage space shuttle forward skirt hardware instead of designing a new structure
- The booster transfers load to the core vehicle through the forward skirt thrust post
- Analysis indicated that the shuttle forward skirt would not meet structural safety factor requirements so testing was commissioned to identify actual capability
- ARAMIS testing was able to provide data when strain gages failed, identify localized high strain near joint welds, and strain at the failure initiation point on the thrust post



High strain spot at crack initiation point

ARAMIS System

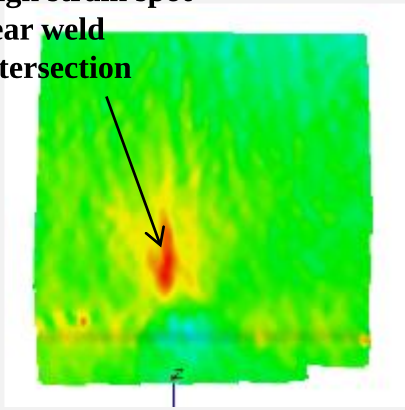
Forward Skirt (top of booster)

Weld (not shown)

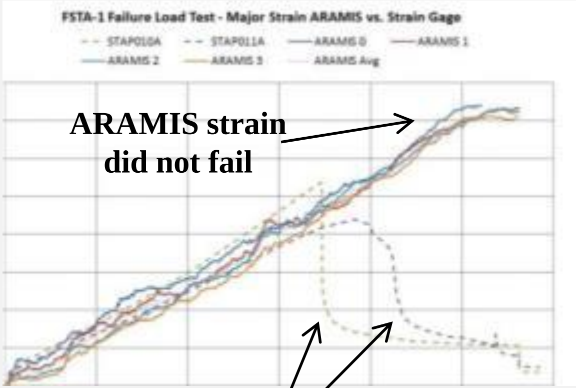
Flight Load Simulation Beam

Thrust Post

High strain spot near weld intersection



Strain Gage Comparisons

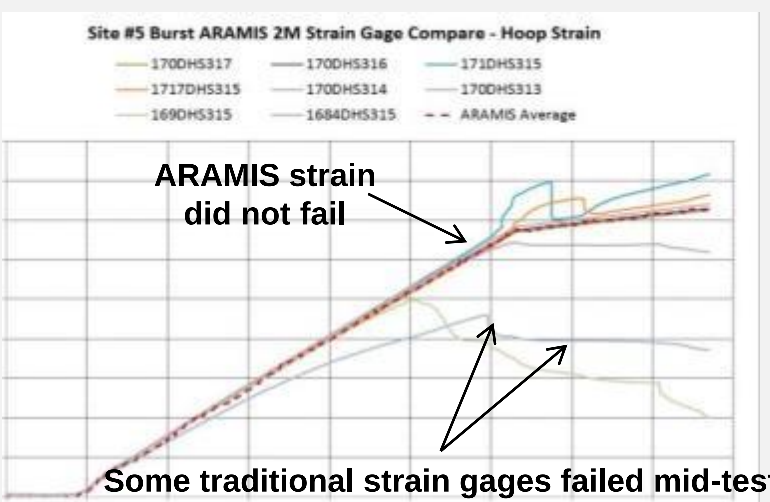


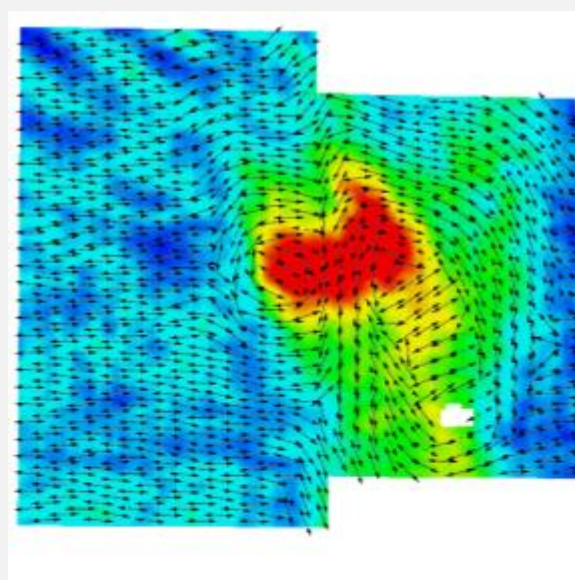
ARAMIS strain did not fail

The traditional strain gages failed mid test

ARAMIS Application: Full-scale NRA Composite Booster Case Burst Testing

- Proof testing followed by a burst test was performed on NASA's Advanced Booster composite case that had been intentionally damaged to varying degrees
  - Risk reduction effort to verify structural safety margins of a damaged motor at varying internal pressures
  - Damage levels were based on the critical impact damage on a composite case that could go undetected
- ARAMIS testing was used to image the damage impact sites where it was not possible to use strain gages
  - Able to detect and correlate unique strain irregularities during the proof and burst tests, but most importantly, was able to show that local strain had not been affected significantly by intentional damage

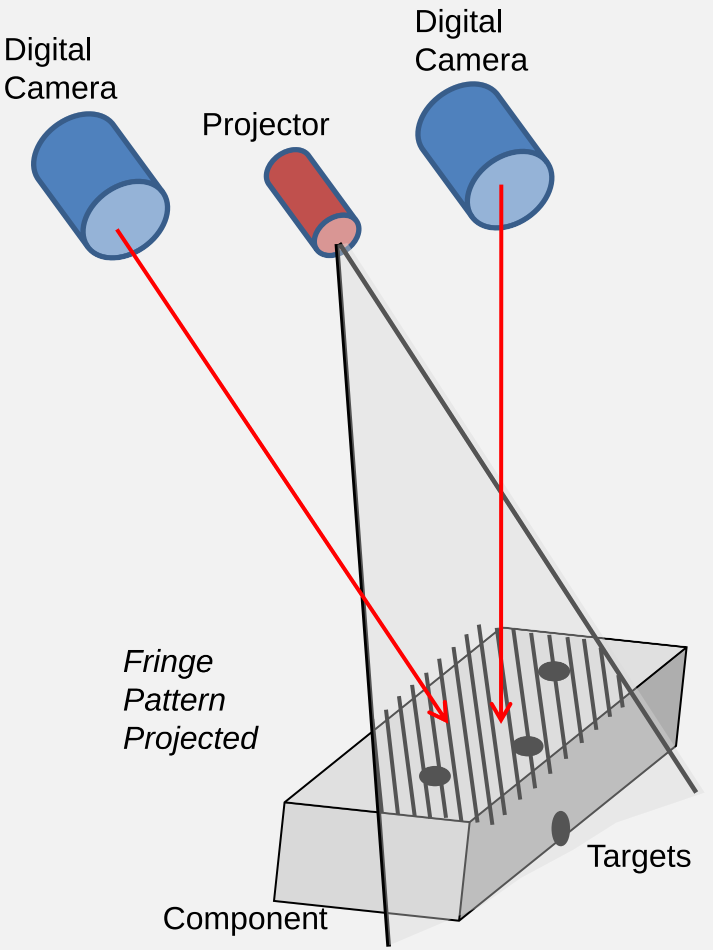




Impact Site: Radial Displacement Contour Plot with Max Principle Strain Vector Overlay

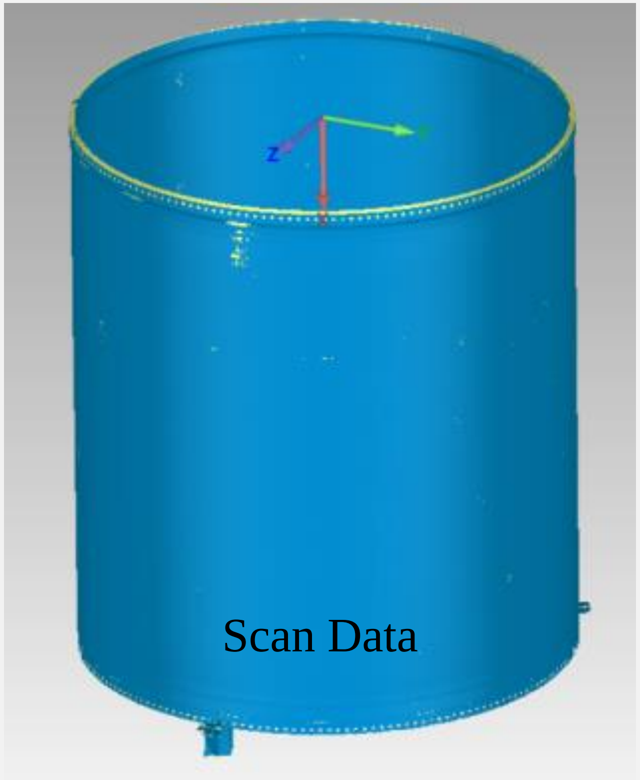
Basics of Structured Light (TRITOP/ATOS) Static Deformation Measurement

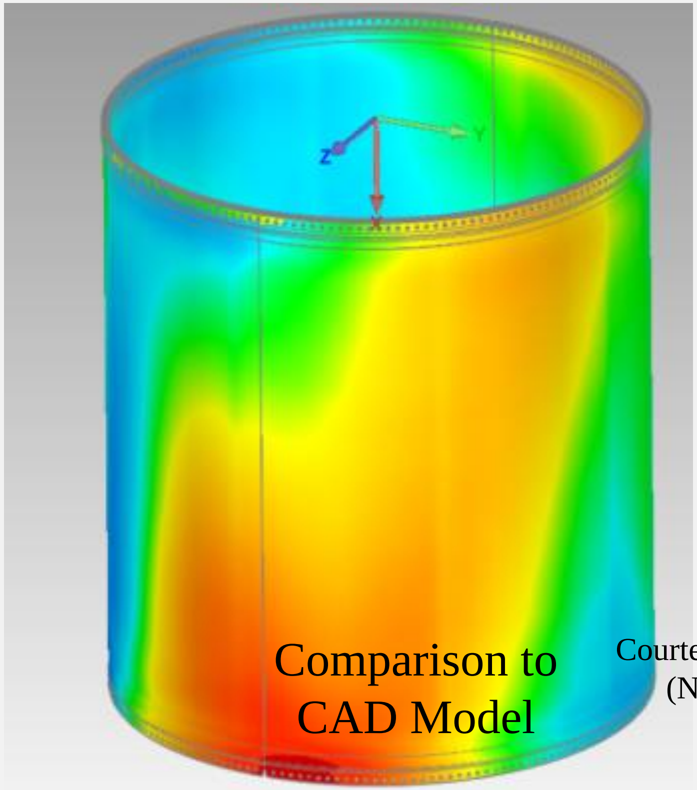
- The Structured Light system is highly mobile and can be customized for lab and field testing
- Structured Light scanning collects full-field 3D surface data of as-built geometry by using stereo cameras to capture a fringe pattern sent out from the central projector
  - ➢ Software triangulates all of the surface data using changes in pixel color
- Photogrammetry is used in conjunction with fringe pattern scanning to provide a 3D point cloud that is essentially a GPS that the scanner uses to precisely triangulate the position of surface pixels to less than 0.001-inch accuracy
- Measurements of pre and post test objects can be compared directly to each other and to a nominal CAD model for comparison to FE model predictions
- Photogrammetry measurements can be used to evaluate displacement vectors at discrete points between pre and post test objects



Structured Light Application: SLS Booster EM-1 & -2 Case Structures Hardware Measurements

- Structured Light is being used to measure straightness of case cylinder hardware as input to FE models for higher fidelity structural analysis predictions
- Aft skirt, forward skirt, and frustum hardware are also being scanned to support motor integration activities
  - ➢ Knowledge of as-built hardware features may prevent costly schedule delays due to inaccurate engineering

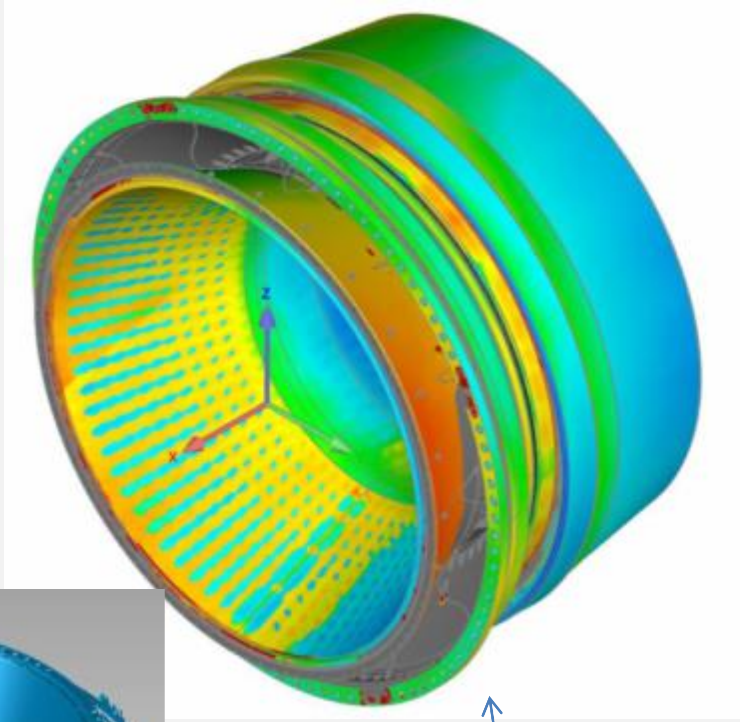


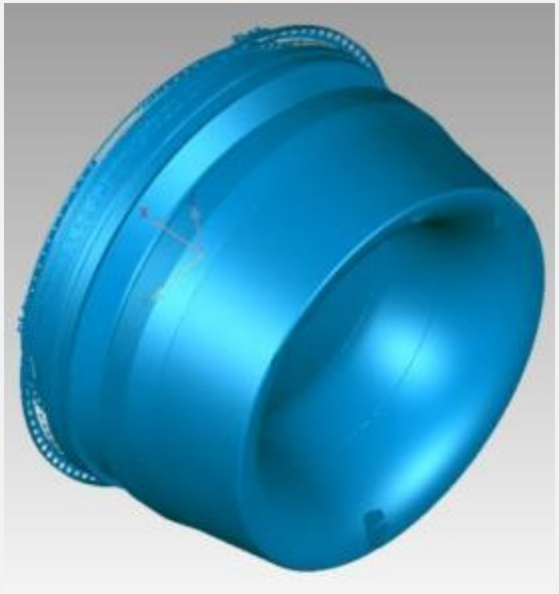


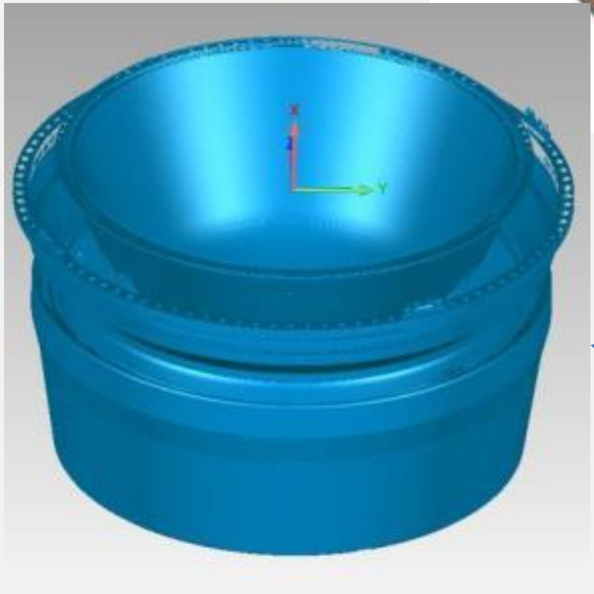
Courtesy of Brian West
(NASA MSFC)

Structured Light Application: QM-1 Nozzle Erosion Measurement

- Using Structured Light for erosion analysis of the QM-1 nozzle provides additional insight into nozzle performance
- Pre-fire comparison of the nozzle to nominal CAD geometry shows deviations between the as-designed configuration and as-built configuration
- Comparison to the post-fire nozzle is pending but will provide an unprecedented 3D view of nozzle erosion performance







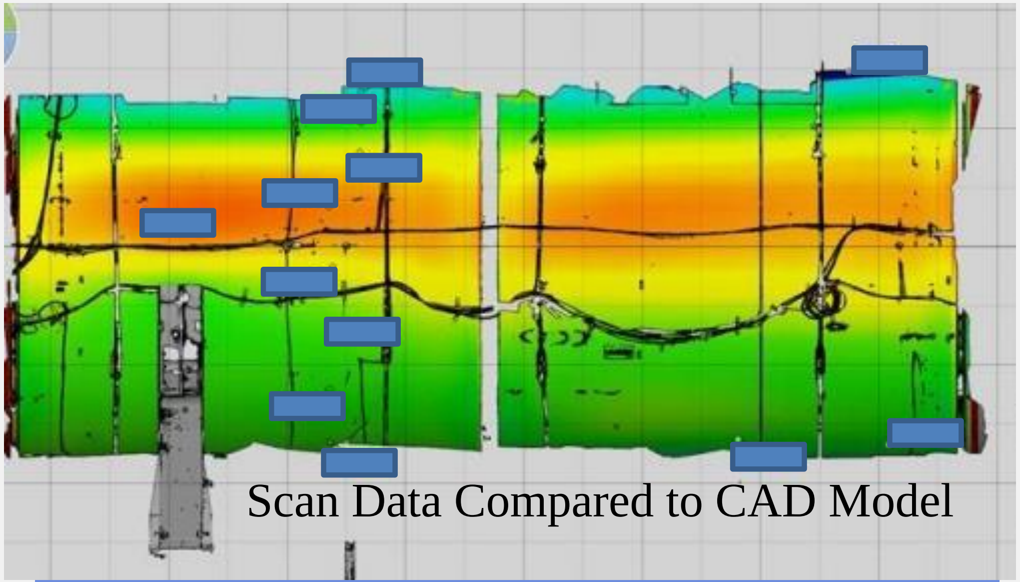
Comparison to CAD Model

Scan Data

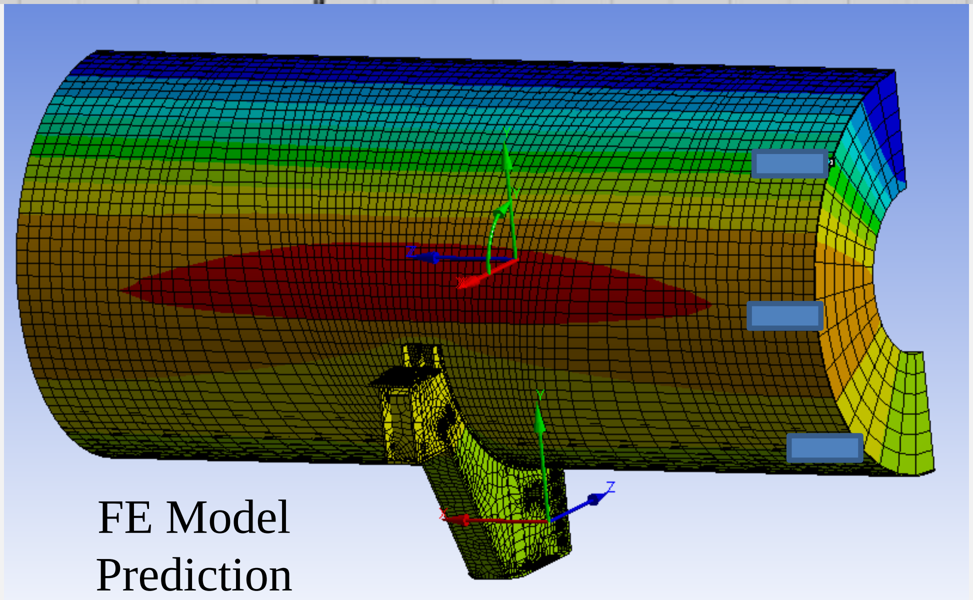
Courtesy of Brian West (NASA MSFC)

Structured Light Application: QM-1 Mid-Span Support Measurement

- Structured Light is currently being used to validate analytical predictions for SLS static test motor case deformation
- Static test motors are supported by chocks during assembly and then by straps just prior to firing
- In the horizontal configuration, the motor case tends to bow outwards creating an egg shape with the largest radial displacement just above the support
- Too high of a support load could cause the case to buckle so it is imperative to validate predictions to truly understand safety margins



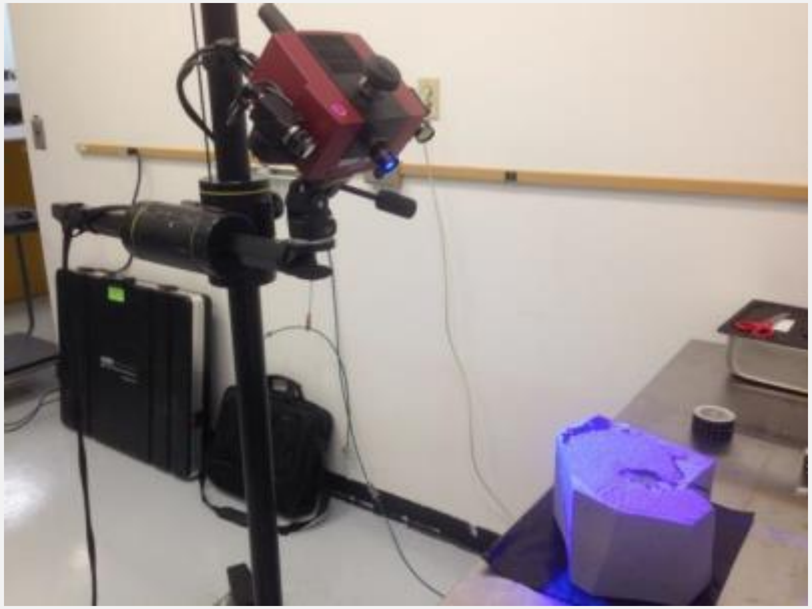
Scan Data Compared to CAD Model



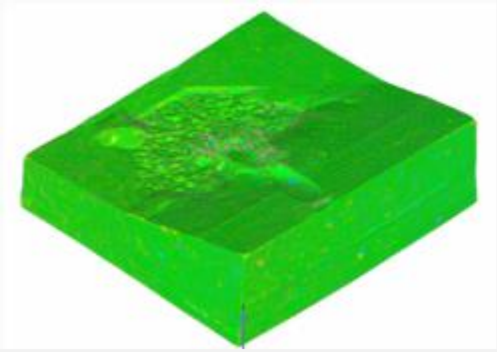
FE Model Prediction

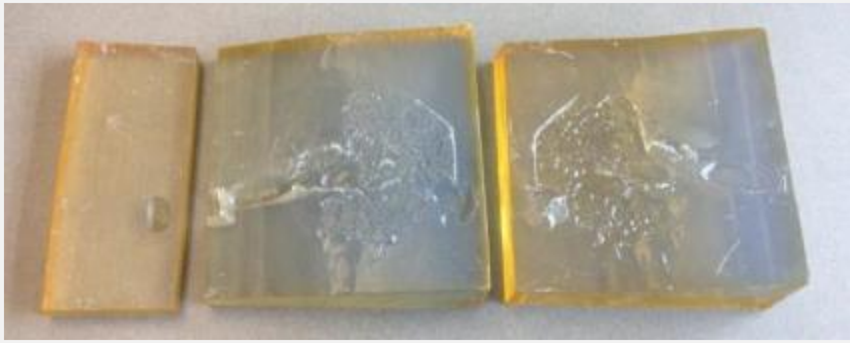
Structured Light Application: QM-1 PLI Unbond Defect Measurement

- An unbond at the liner and propellant interface was caused by insulation off-gassing during processing of the QM-1 aft segment, resulting in a significant failure investigation
- Structured Light was used to scan a PLI unbond dissected from one of the defective aft segments
- The scan data was used to 3D print a replica of the defect for preservation and engineering evaluation



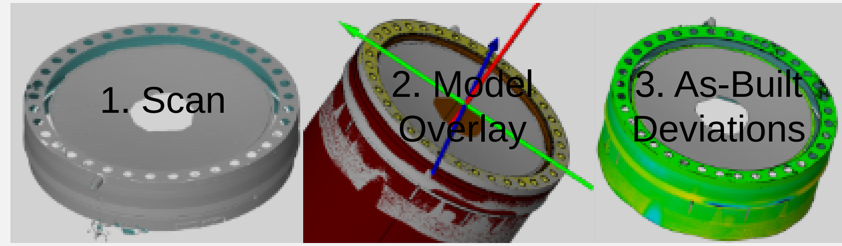
Courtesy of Brian West (NASA MSFC)

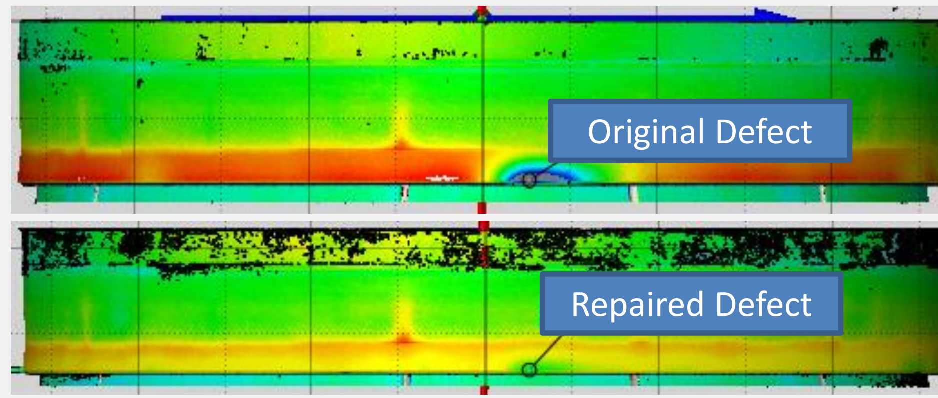


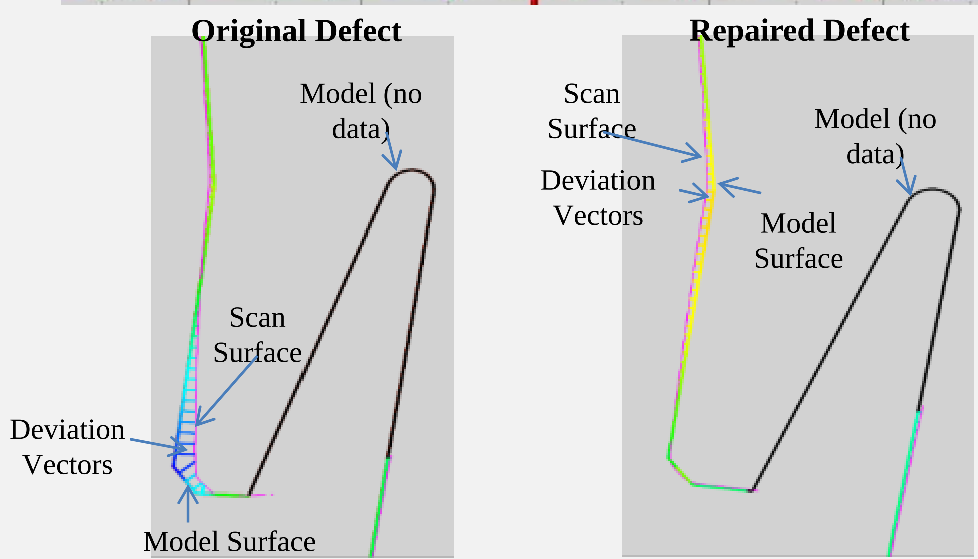


Structured Light Application: SLS Booster Igniter Defect Investigation

- Following a motor static test, evidence of an anomalous hot gas path was discovered at the igniter thermal barrier
- Structured Light inspection of other igniters manufactured at the same time revealed intermittent localized deformation on the mating surface
- A series of tests were performed with custom tooling to simulate variations in dome mating while concurrent evaluations were performed to repair the defects
- Structured Light identified the root cause and validated the effectiveness of the corrective action





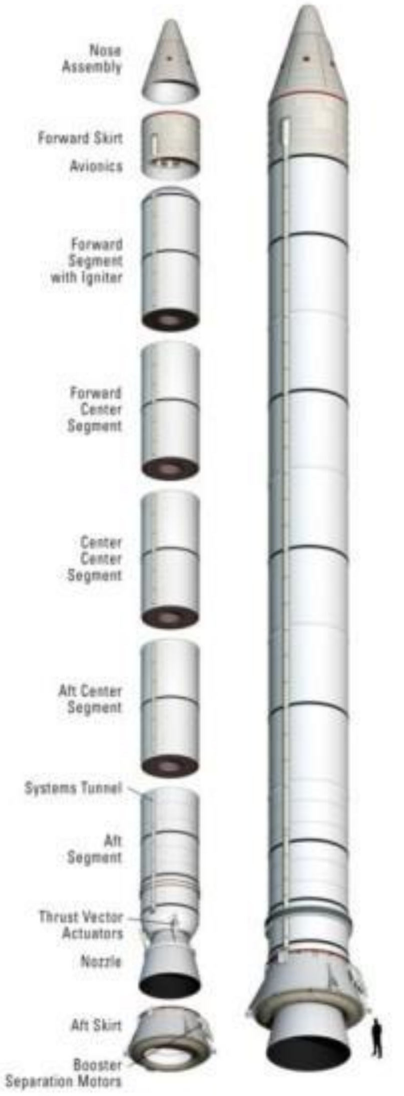


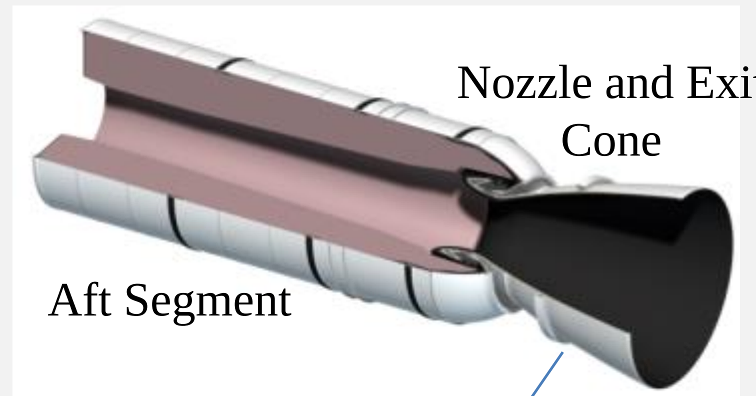
Conclusions

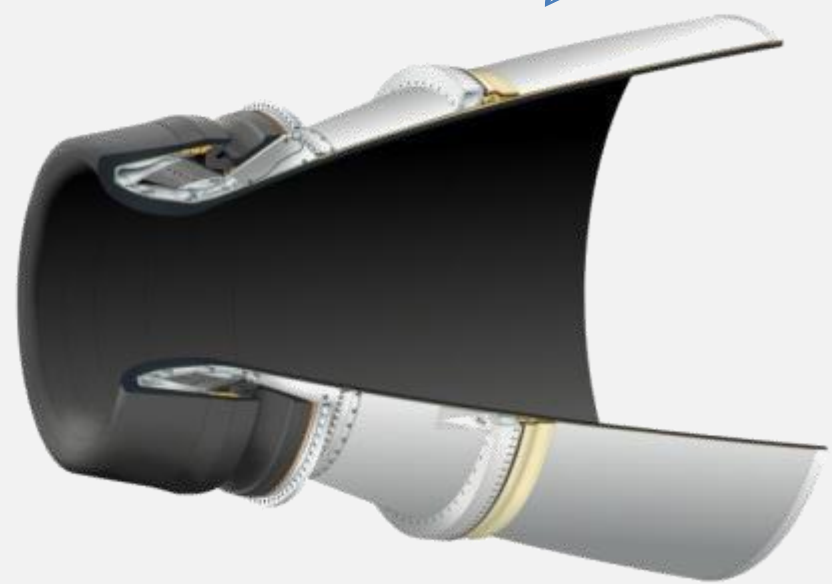
- ARAMIS is a mobile full-field 3D dynamic deformation measurement and analysis system
  - Provides information far beyond typical strain gages and is not limited to strain measurement in a discrete location
  - Technology is scalable so it can be applied from a microscopic to macroscopic level
  - Most valuable for validation and optimization of FE model predictions to better define structural margins of safety
- Structured Light is a mobile full-field 3D scanning system capable of static deformation measurement and analysis and as-designed to as-built deviation analysis
  - Method is more rapid and less data-intensive than laser scanning or traditional CMM methods and has greater analysis software capabilities
  - Most valuable design verification, inspection, and reverse engineering but also quite useful for FE model validation and optimization

Back Up: SLS Vehicle Design Overview

SLS Booster







Back Up: Other Applications

- ARAMIS:
  - Material testing
  - Strength assessment
  - Component dimensioning
  - Examination of nonlinear behavior
  - Characterization of creep and aging processes
  - Determination of Forming Limit Curves (FLC)
  - Verification of FE models
  - Determination of material characteristics
  - Analysis of the behavior of homogeneous and inhomogeneous materials during deformation
  - Strain computation

- Structured Light:
  - Manufacturing
  - Process development
  - Quality acceptance
  - Digital assembly
  - Reverse engineering
  - Inspection
  - Pre and post test configuration
  - Facilities modeling

Questions?